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LOS ALAMOS LASER EYE INJURY INVESTIGATION

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Abstract

A student working in a laser laboratory at Los Alamos National Laboratory sustained a serious retinal injury to her left eye when she attempted to view suspended particles in a partially evacuated target chamber. The principle investigator was using the white light from the flash lamp of a Class 4 Nd:YAG laser to illuminate the particles. Since the Q-switch was thought to be disabled at the time of the accident, the principal investigator assumed it would be safe to view the particles without wearing laser eye protection. The Laboratory Director appointed a team to investigate the accident and to report back to him the events and conditions leading up to the accident, equipment malfunctions, safety management causal factors, supervisory and management action/inaction, adequacy of institutional processes and procedures, emergency and notification response, effectiveness of corrective actions and lessons learned from previous similar events, and recommendations for human and institutional safety improvements. The team interviewed personnel, reviewed documents, and characterized systems and conditions in the laser laboratory during an intense six week investigation. The team determined that the *direct* and *primary* failures leading to this accident were, respectively, the principle investigator's unsafe work practices and the institution's inadequate monitoring of worker performance. This paper describes the details of the investigation, the human and institutional failures, and the recommendations for improving the laser safety program.

Introduction

The Los Alamos National Laboratory (LANL) Director had just completed a mandatory all hands briefing on the morning of July 14th to convey the seriousness and implications of the classified removable hard drives that had been reported missing the previous week. In this briefing, the Director had stressed the importance of following safety and security procedures. A student was injured while

working in a laser laboratory about an hour after the Director's briefing. The incident was not reported until the end of the following day. The Laboratory Director, in a memorandum dated July 16, 2004, established a team to investigate and report on the incident. The Accident Investigation Team (the Team) conducted its investigation July 19 – August 27, 2004.

Scope of Investigation

The scope of the investigation was to:

- (1) review and analyze the circumstances of the accident
- (2) determine the causes of the accident
- (3) make recommendations.

Methodology

The Team used the following methodology:

- Inspecting and photographing the accident scene and individual items of evidence related to the accident
- Gathering facts through interviews and reviews of documents and evidence
- Conducting technical evaluations and measurements of the experiment being conducted when the accident occurred
- Reviewing emergency and medical response
- Using events and causal-factors analysis, barrier analysis, and fault-tree analysis to correlate and analyze facts and identify the accident's causes
- Based on analysis of the information gathered, developing recommendations to prevent recurrence

Report

The details of the investigation were published in LANL Investigation of a Laser Eye Injury (LA-UR-04-6229). The report is available to the public.

Investigation Team Members

The Team consisted of a Chair, Vice Chair, three trained accident investigators, three experienced laser users, a laser safety officer, four consultants, three observers, and an independent reviewer.

Laser Accident

A student (S1) was working as a guest affiliate on a research program to analyze soil samples in a partial vacuum. The principal investigator (PI) was a well known scientist who had developed a Laser Induced Breakdown Spectroscopy (LIBS) process that was suitable for this type of analysis. The PI had been employed at LANL for 23 years and was the recipient of 4 R&D 100 awards.

Experimental Setup

Simulated soil samples were placed in a sealed target chamber that was subsequently evacuated to about 7 torr. The objective of the particle-in-vacuum (PIV) experiment was to demonstrate that particles of the simulated soil could be suspended by focusing pulsed laser energy from a secondary laser (L2) onto the sample. The primary LIBS laser (L1) could then be used to vaporize and analyze the particles. Both lasers were pulsed Nd:YAGs operating at 1064 nm. The LIBS laser (a Spectra Physics Quanta Ray INDI Q-switched laser) was externally triggered by a Stanford Research Systems (SRS) pulse generator so that it could be synchronized with the spectrum analyzer. The PI further intended to use the white light from L1's flash lamp to illuminate the suspended particles in order to verify their presence. He reasoned that this could be accomplished by disconnecting L1's External Q-Switch Trigger input from the SRS pulse generator while leaving the External Flash Lamp Trigger input connected, and viewing the illuminated particles through the back window of the target chamber.

Alignment

On 13 July the PI aligned L1 such that its beam was reflected off a turning mirror, through a focusing lens, through the front window of the target chamber, and was focused in the center of the target chamber. The secondary laser was mounted on a shelf above the optical table. The PI aligned the L2 beam such that it reflected off a turning mirror, through a second focusing lens, through the top window on the target chamber, and was focused on the soil sample. The

alignment was reportedly accomplished with the lasers operating at low power in the long pulse (normal) mode. The PI did not check for stray beam reflections.

Experiment

After the lunch break that followed the Director's all hands briefing, the PI and S1 entered the laboratory to perform the PIV experiment. S1 prepared a soil sample and placed it in the target chamber. She then sealed the chamber and established a partial vacuum inside it. The PI turned on the power supplies for L1 and L2 and turned the laboratory laser warning lights to yellow, indicating that power was on to Class 4 lasers. The PI connected the SRS pulse generator to L1's external flash lamp trigger input. He then turned L1's flash lamp intensity knob to a position that had been previously marked for 40 mJ per pulse when operating in Q-switched mode. The PI did not measure the output of L1 and did not verify the alignment. Neither the PI nor S1 were wearing laser eye protection. The PI closed his eyes and turned L2 on at 10 pulses per second in the Q-switched mode to suspend particles in the target chamber. He then asked S1 to turn the room lights off so he could see if suspended particles were being illuminated. The PI removed the beam stop at the back window of the target chamber, bent down slightly, and said he could see the particles.

Laser Eye Injury

The PI then invited S1 to take a look. The student leaned in to look at the target chamber. She saw a bright flash in her left eye and immediately drew back. She told the PI that she had seen a bright flash and had what appeared to be a reddish brown amoeba like floater in her left eye. The PI told her that she was probably just seeing an afterimage like she might get from looking at a flash bulb. He suggested they keep working and see what happened. The PI then turned down the flash lamp intensity knob on the L1 power supply. The PI and S1 began to reconfigure the experimental setup so that the spectrum analyzer could look into the vacuum chamber. About a half hour after the incident the student said she was still experiencing visual problems and asked if LANL had an eye doctor. The PI called HSR-2 (LANL's Occupation Medicine group) and drove S1 to the clinic.

HSR-2 Examination

The PI told the Physicians Assistant (PA) that an eye injury had occurred while working in a laser lab, but it was not a laser injury because the laser was off. The PA diagnosed the injury as a nonoccupational detached retina based on the PI's insistence that the laser was off. The PA made an immediate appointment for S1

with an eye specialist in Los Alamos. The PI then drove S1 to see the eye specialist.

Eye Specialist Examination

After examining S1, the eye specialist suspected a laser eye injury, but could not make a positive diagnosis. He arranged for S1 to see a retinal specialist in Santa Fe the next morning.

Return to Work

The PI and S1 drove back to work. S1 went home after a short while. The PI returned to the laser laboratory to make some measurements. When he left work, the PI stopped by his Group Office to discuss the incident with his Acting Group Leader (AGL), but no one was there.

Retinal Specialist Examination

The next morning, the PI drove the student to see the retinal specialist in Santa Fe. The retinal specialist diagnosed the injury as a laser eye injury.

John's Hopkins Hospital Evaluation

The Los Alamos eye specialist accompanied S1 to Johns Hopkins Hospital in Baltimore, MD, on 21 July for further evaluation. Johns Hopkins determined that the laser accident had caused a hole in the student's retina. The hole was measured to be about 400 microns in diameter and about 250 microns deep. At this depth, seven layers of the retina were vaporized, but a tiny bit of the choroid may remain in place. The hole is in the macula and extends almost to the macula's center. Although, it is not centered exactly on the fovea, the fovea may be damaged. Since the hole extends into the choroid, there was some hemorrhaging near the hole and some hemorrhaging into the vitreous fluid below the fovea.

The student's visual acuity was measured at 20/100 with the left eye and 20/20 with the right eye. The injury is currently causing blurring of the central vision of the left eye and some difficulty with depth perception. Peripheral vision in the left eye remains intact. The student is experiencing some difficulty with reading but was able to finish writing a report on her project. She has no restrictions concerning driving, reading, taking classes, or using a computer.

Guarded Prognosis

The injury has resulted in permanent loss of the central vision in the student's left eye. The macular hole is healing and there is no wrinkling of the retinal tissue. Surgical macular hole repair will not be necessary. There has been no improvement in the student's depth

perception. It may take up to a year to determine the final outcome of the student's eye injury.

Time of Injury

The following occurred in S1's left eye immediately after the eye's exposure to bright light from L1 on July 14, 2004:

- A sudden change in visual acuity
- A floater resembling a "jellyfish"
- Acute, bright-red blood over the retinal lesion

Based on those factors, the preponderance of medical evidence indicates that S1 suffered the injury to her eye on July 14, 2004.

Reporting the Accident

The accident was not reported immediately to line management or the laser safety officer in violation of LANL's occurrence reporting procedures.

Report to Group Leader

After the examination by the retinal specialist on the morning of 15 July, the PI called his AGL and told him there had been an accident in the laser laboratory. The PI and S1 met with the AGL about 11 am when they returned from Santa Fe. They discussed the accident and the AGL said he would write something up for the division office. The student returned to work and the PI returned to the laser laboratory to make some more measurements.

Initial Report to C-Division Office

After the phone call from the PI, the AGL called the C-Division Chief of Staff (CDCS) to report the accident (He assumed the C-Division Leader (CDL) was busy). He told the CDCS that a student had gotten something in her eye in a laser laboratory. The CDCS asked if the accident was reportable. The AGL said he didn't think it was reportable. The CDCS told the AGL it was very important to get definitive information to the CDL as soon as possible.

Later that afternoon, the CDCS informed the CDL that a student had gotten something in her eye in a laser laboratory and was taken to see a doctor, but was back at work so the incident was not reportable.

HSR-2 Reporting

Although she was still under the impression that the event was nonoccupational, the HSR-2 nurse had been inquiring about the student's condition on the morning of 15 July. The PI returned her call in the mid

afternoon and told her that the retinal specialist had diagnosed a laser injury. The PI again insisted that the laser was not pulsing. The nurse did not understand the technical terms used by the PI, so she called the LANL Laser Safety Officer for clarification. The LSO told her that either the laser was pulsing or that someone was lying. The nurse informed her Group Leader of the phone conversations with the PI and the LSO.

The HSR-2 Group Leader immediately called the LANL associate director for operations (ADO) and the Santa Fe retinal specialist. The ADO then took action by notifying Group PS-7 (Occurrence Reporting).

Official Report to C-Division Office

The AGL wrote up the event as requested by the CDCS and had the PI and S1 review it for accuracy before he submitted it to the C-Division Office. He transmitted the write up to the CDCS by e-mail at 5:23 pm. However, the CDCS had gone home at 4:00 pm so the e-mail failed to notify anyone.

PS-7 Notification

The PS-7 Group Leader called the CDL at 5:30 pm and asked if he knew he had a laser accident in one of his laboratories the previous day. He then met with the CDL and the C-Division operations group leader in the CDL's office to discuss the incident. During this discussion, the ADO called the deputy associate director for strategic research (ADSR) to inform him of the laser accident in one of the divisions in his directorate and then called the CDL at 6:00 pm.

Los Alamos National Laboratory Stand Down

On the morning of 16 July, PS-7 personnel conducted a critique of the event in the laser laboratory where the accident had occurred. The Laboratory Director was notified of the laser accident that morning as he was returning from travel. He promptly ordered the entire Laboratory to stand down all operations and appointed The Team to investigate the accident.

Scene of the Accident Not Preserved

As a result of the delays in reporting the accident coupled with the stand down of Laboratory operations, the scene was not secured until the following Monday morning (19 July).

Investigation

The Team quickly developed a plan of action for conducting interviews with the principals involved, inspecting the laser laboratory, reviewing relevant work control and hazard mitigation documentation,

making measurements in the laboratory, and performing the analyses necessary to determine the causes of the accident.

Personnel Interviews

The interviews were conducted by the trained and experienced PS-7 personnel. Requests for clarification or more technical details were made by the technical experts on The Team. Each principal was asked to relate their recollection of events leading up to and following the laser accident. The information given by each interviewee was reviewed and compared to that given by other interviewees for consistency and accuracy.

Principal Investigator

The PI described his intent for the overall PIV / LIBS experiment and the way he works with lasers in the laboratory. His description of Q-switched operation of L1 was incomplete and inconsistent. He gave conflicting descriptions of his alignment procedures and his use of interlocks, warning lights, and laser eye protection.

During one interview the PI reported that he had aligned the laser while it was operating in the long pulse (normal) mode at low power and that he wore laser eyewear. During the next interview he stated that he was doing the beam alignment using the white light from the flash lamp only because he had disconnected the external trigger to the Q-switch, so he didn't need to wear laser eye protection. As proof that the laser was not lasing, he said that the spot on the phosphor card he used for alignment was white. During another interview he recalled that it was difficult to see the faint white spot on the phosphor card even when the room lights were turned off.

The PI reported that he used interlocks and warning lights during laser operations. He stated that when he set the warning lights to red the door interlocks shut down laser operations when the door to the laboratory was opened.

The PI made conflicting statements concerning the Q-switch, flash lamp, and flash lamp intensity settings on the L1 power supply, and the connections on the external flash lamp and Q-switch triggers as they existed during his alignment on 13 July and at the time of the accident on 14 July.

Students

The PI served as mentor to two undergraduate students that were involved in experiments leading up to the accident. The students reported that they had taken the

LANL online laser safety training class. They said they learned that there were 4 classes of lasers, that Class 4 lasers were the most dangerous, that they should wear laser eye protection whenever a Class 4 laser was on, and that they should never look at the laser beam. The students stated that the PI told them that they didn't need to wear laser eye protection once the beam was aligned. The students said the PI didn't wear laser eye protection during beam alignment and that the laser spot on the phosphor card he used was always red. After a short while, the students adopted the PI's practice of not wearing laser eye protection.

The students stated that the PI taught them how to set up experiments, make measurements, and record data. After a few weeks they were allowed to work together without his presence. They stated that while running laser experiments (with the warning lights set to red) the PI entered and exited the laboratory without causing the lasers to shutdown.

The student who was injured did not understand the hazards in attempting to see the suspended particles using the white light from L1's flash lamp. She believed that L1 was not lasing because the PI, her mentor, had told her so. She further believed that if L1 had been lasing, its beam would be focused on the particles in the center of the target chamber and therefore would not exit through the rear viewing window. S1 also thought it was safe to look into the target chamber through the rear window because the PI had just done so before inviting her to do the same.

Group Leaders

The AGL had been serving in an acting capacity for about 6 months. He was pleased with the scientific achievements of the PI and inferred that his safety practices were as good. When asked specifically, the AGL could not remember seeing the PI wear laser eye protection in recent years. He had not walked through the PI's laboratory since he became the AGL.

The previous group leader stated that he had walked through laboratories regularly, but had concentrated on those he considered most hazardous. He had not walked through this laboratory.

Co-Workers and Peers

A co-worker stated that the door of the laser laboratory was sometimes open during laser operations. He saw the PI and students were not wearing laser eye protection and cautioned them about the non use of laser eye wear and the misuse of interlocks. The students put their eyewear on but the PI ignored him. The students eventually quit wearing their eyewear as well.

Co-workers and peers generally respected and admired the PI for his scientific accomplishments, reputation, and awards. They generally thought his safety practices were good. When asked specifically, none could remember seeing the PI wearing laser eye protection during laser experiments in recent years. Those who had worked more closely with the PI had adopted his laser safety practices.

Laser Laboratory

The laser laboratory has two entrances, one with a double door providing access from the hallway and one with a single door providing access to an adjoining laboratory. Both entrances have laser warning light panels and magnetic switches for the interlock system. The Team observed a general state of poor housekeeping in the lab. The area around the optics table was partially blocked by diagnostics on an additional table that had been positioned against the optics table and also by a gas cylinder and a vacuum pump. Egress from the back side of the optics table was severely limited. Laser eye protection was available for use throughout the lab, although the optical density (OD) rating labels on some were worn and therefore difficult to read.

Accident Scene Not Preserved

The accident scene was not preserved. Immediately after the accident the PI and S1 began to reconfigure for the full PIV / LIBS experiment. This involved some changes in connection of the vacuum pump and a CO₂ cylinder, the optical path from the spectrum analyzer to the target chamber, and the settings on the L1 power supply. In addition, the PI returned to the lab at least twice to make measurements to determine the cause of the accident. The PI stated that the optical elements in the beam paths for L1 and L2 were not altered by this activity.

Laser Energy Measurements

Post accident measurements were made under the supervision of The Team in the lab on 11, 12, 16 and 23 August. The operating modes for L1 producing pulsed laser energy were established. The L1 flash lamp intensity was set to produce 40 mJ in the Q-switched mode (stated condition at the time of the accident. Measurements were made with L1 operating in the Q-switched mode, long pulse (normal) mode and in the flash lamp only (Q-switch not triggered) mode.

The L1 laser energy and beam diameter were measured at various points in the beam path. The energy density at 12 inches from the target chamber (the probable position of the student's eye) was calculated and is shown in the Table 1 below.

Table 1 Energy Density at Student's Eye

Laser Mode	Energy Density
Flash Lamp Only	0.22 $\mu\text{J}/\text{cm}^2$
Q-Switched	4.2 mJ/cm^2
Long Pulse	5.2 mJ/cm^2

The intrabeam maximum permissible exposure (MPE) for the eye from a Q-switched Nd:YAG laser at 1064 nm is 5 $\mu\text{J}/\text{cm}^2$. At 12 inches from the rear chamber window, operating in simmer mode (flash lamps only, no lasing), the energy density is only 4% of the MPE. At the same position in long-pulse mode, the measured energy density is 1040 times the MPE. In Q-switched mode it is 840 times the MPE.

The Team concluded that L1 was producing the pulsed laser energy that injured the student's eye, contrary to the claims made by the PI. The Team determined that with the Flash Lamp Mode Selector set to External as claimed by the PI, the Q-Switch Mode Selector had to be set to one of three modes (External, Long Pulse, or Q-Switch) to produce pulsed laser energy. The Team concluded that the laser was operating in one of the following scenarios at the time of the accident:

1. The Q-switch trigger cable was connected to the SRS pulse generator and was triggering L1. The PI could not consistently recall the cable configuration after he completed the alignment on July 13 and before work began on July 14.
2. With the flash lamp trigger cable connected to the SRS pulse generator and the Q-switch trigger disconnected, the Q-switch mode-selector switch on the front of the power supply was set to the Long Pulse mode.
3. With the flash lamp trigger cable connected to the SRS pulse generator and the Q-switch trigger disconnected, the Q-switch mode-selector switch on the front of the power supply was configured to operate in Q-Switched mode.

The L2 laser was mounted near eye level on a shelf above the optical table. The L2 beam was reflected downward toward the target chamber by a turning mirror that was fastened to the shelf by a C clamp. The L2 laser was found to be defective. Only 3 sporadic pulses were generated in a 10 minute period. These pulses were measured at about 300 μJ per pulse. Since this would be insufficient energy to suspend particles in the target chamber, it is probable that the particles were suspended by the action of the vacuum pump.

Beam Path and Stray Reflections

The Team used an IR viewer to characterize the beam path and stray reflections. The L1 beam was reflected at a right angle to the focusing lens by a dichroic turning optic on a kinematic mount. The focusing lens mount clipped the beam and created a rapidly diverging stray beam that was sent upward and backward toward the aisle around the optics table.

The laser beam was centered low on the focusing lens and was steered upward through the target chamber. With the beam stop was removed, the laser beam was partially intercepted by a metal cabinet 36 inches from the target chamber's rear window. The diverging beam was about 5 inches in diameter (Figure 1) where it impinged on the cabinet at about eye height for S1.

Figure 1 IR Image of Laser Beam



Part of the L1 beam continued on and hit a pressure gauge mounted on the back wall (83 inches from the target chamber's rear window) at a height of about 59 inches.

The back reflection from the focusing lens (Figure 1) crossed the aisle and impinged on the front wall at a similar height. This reflection was measured to be about 12% of the incident beam.

Laser Interlocks and Warning Lights

The L1 laser was connected to a manually operated laser interlock system designed to turn off L1's flash lamps and prevent lasing when either lab door was opened. The laser interlock system also included an emergency "Off" switch. The L2 laser was not connected to the interlock system because it could only accommodate one laser. One of the interlock connections was held together with scotch tape. A

bypass box had been installed that could be used to override the interlock system and allow the laser to continue running while either or both doors to the lab was open. The Team discovered and measured a potential difference of 12 Vdc between the bypass box and the optics table. This condition was found by observing sparks between the box and optics table.

The laser warning lights were three light (green, yellow, red) panels that operated independently of the interlock system. The warning lights worked properly when manually set to indicate the laser operating conditions. Due to the independence of the interlock system and the bypass box, these lights functioned as indicators of the manual setting on the panel, not the actual operating condition of the laser.

Work Control Documentation

Hazard Control Plan

The work control documentation covered the basic LIBS experiment. A hazard control plan (HCP) had been developed several years earlier. The HCP identified the hazards that could be encountered in performing a LIBS experiment and listed the control measures required to mitigate the hazards. The HCP had been reviewed and approved in October of 2003.

Integrated Work Document

The Integrated Work Document (IWD) for the LIBS experiment tabulated the hazards, controls, applicable documents, and training necessary for performing each step of the experiment. The steps listed in the IWD were very general and did not reach the procedural level (Step 1: Design the experiment; Step 2: Set up the experiment, etc.). The lack of detail in this document resulted in a failure to fully assess the hazards and to implement the necessary mitigating controls for performing the experiment safely. The IWD could only apply to a very generic LIBS experiment. The IWD was reviewed in December of 2003 and approved by the group leader and the interim laser safety officer (LSO) in spite of the lack of detail. Due to a series of personnel transfers and job changes, several different LSOs were involved at different phases of this experiment. At the time of the IWD review, C-Division did not have an assigned LSO and they called in an interim LSO from another division. The group leader noted that another review would be required if the HCP was revised.

Viewing Suspended Particles

The act and the means of viewing the suspended soil sample particles were not addressed in either the HCP or the IWD. This experiment is outside the scope of

the existing work control documentation. The PI failed to realize that using the unprotected eyeball to view suspended particles illuminated by a Class 4 laser operating with its Q-switch disabled constituted a new experiment and required a new hazard evaluation and new mitigation controls. Consequently, this act became an unspecified and un-analyzed part of Step 2: Set up the experiment.

Failure to Conduct Pre-Job Briefing

The IWD is used to conduct the pre-job briefing. The person in charge uses the IWD to describe each step of the experiment and the hazards, the mitigating controls, the applicable documents, and the training necessary to perform the experiment safely. Following the pre-job briefing, the workers are asked to sign the IWD, indicating that they will follow the work steps, implementing the required controls, that they will stop work when hazards or conditions change, and that they are qualified and fit to do the work. The PI did not conduct the required pre-job briefing. He handed the IWD for the LIBS experiment to S1 the day after the accident and asked her to sign it and date it with the date she used when she read the HCP, over 2 weeks earlier. He then asked the second student to sign the IWD and use the same date as S1.

Laser Safety Training

The students had completed the required LANL online laser safety training and understood that they were supposed to wear laser protective eyewear whenever the Class 4 lasers were on and that they should never look at the laser beam. The PI failed to reinforce this training. He modelled bad laser safety practices with respect to laser protective eyewear and interlocks. The students were influenced by the behavior of their mentor and eventually adopted his practices.

Failure to Obtain Baseline Eye Examinations

The PI failed to identify and register the students as laser workers requiring baseline eye examinations. The baseline eye exam is a prerequisite for laser workers at LANL. The PI and line management failed to ensure that the students had completed all the prerequisites for work with lasers.

Ineffective Performance Monitoring

Safety responsible line managers did not adequately monitor the PI's performance and did not ensure the effective implementation of LANL's Laboratory Implementation Requirement regarding laser safety (LIR 402-400-01.3). This LIR defines the roles and responsibilities for implementing the laser safety standards set forth in ANSI Z136.1. Specific control

measures are recommended in LANL's Laboratory Implementation Guidance (LIG 402-400-01.3).

The PI's behavior, combined with a failure to implement many of the controls recommended in the LIG resulted in an unsafe work environment conducive to accidents. The PI's line managers did not detect and correct his unsafe work environment. They did not directly monitor the PI while he was performing laser operations, did not provide sufficient oversight of his work planning and execution to ensure compliance with and implementation of existing requirements, and did not ensure the safety of students assigned to the PI. The PI's line managers inferred his safety performance from his world-class technical performance, his lack of prior mishaps, and his many awards.

Analyses

The Team developed an Event and Causal Factor Chart, and used Barrier Analysis and Negative Fault Tree Analysis to determine the causes of the accident.

Direct Causes

The Team determined the direct cause of this accident was the PI's failure to perform work in accordance with established safety standards, processes, and procedures. The PI's failure to practice, model, and enforce safe behavior directly influenced the student and resulted in the eye injury. Specific actions and inactions leading to the accident were:

- Neither the PI nor S1 was wearing laser eye protection, and there were no engineered safety measures.
- The PI did not recheck beam alignment or laser condition or check for beam reflections on July 13 or 14.
- The PI prepared an insufficiently detailed integrated work document and did not resubmit a modified hazard control plan to reflect experimental changes.
- The PI did not give S1 proper pre-job training, and he asked S1 to sign and predate the IWD after the accident.

Primary Failures

The Team determined that the primary failure of this accident was the fact that the existing institutional policies and practices regarding performance monitoring were not effective. The Team also determined that existing institutional policies and practices about work planning and execution are adequate to have prevented the accident from

occurring, but they were not effectively implemented. Specific failures leading to the accident were:

- Safety-responsible line managers did not monitor the PI's safety practices or his workspace and did not ensure his adherence to Laboratory Implementation Requirements, Laboratory Implementation Guidance, and C-Division work/worker authorization procedures.
- Safety-responsible line managers and the laser safety officer signed the PI's IWD without noting the lack of detail.
- Management did not ensure that S1 completed all prerequisites for work.
- LANL's Student Mentoring Program did not require mentor training or monitor students and their mentors.

Observations and Concerns

During the investigation, the Team identified deficiencies in processes, programs, and procedures. While these deficiencies did not prove to be causal, they do present improvement opportunities. Among those were:

- The Laser Safety Officer program does not ensure that LSOs have the necessary experience and knowledge to effectively carry out their duties and responsibilities.
- The laser safety training program does not place enough emphasis on avoiding direct exposure, especially eye exposure, to the beam. Training states that personnel must "avoid looking directly at the beam." Emphasis should be on keeping eyes away from the beam's axis. Additionally, the Team questions the appropriateness of online self-study as training for a high-hazard activity such as operating a Class IV laser.
- The accident scene was not promptly secured and controlled after the accident. This failure hindered the Team's ability to accurately determine the scene's status and configuration at the time of the accident.

Recommendations

Recommendations made by the Team to address LANL's institutional shortcomings revealed by this investigation are detailed in the investigation report and are specific to LANL. These recommendations, however, are intended for the laser safety community:

- 1) Do not infer or assume laser safety practices based on the reputation or technical achievements of the laser user.

- 2) Do not assume a laser user is going to follow the steps in the approved procedure.
- 3) Ask the experimenters if they actually use their laser safety control measures.
- 4) Ask the experimenter what might be changed in the experimental set up if the results of a given step are not as expected.
- 5) LSOs should have a greater presence in the laboratory.
- 6) Laser safety training must emphasize not looking at the laser beam and not placing one's eyeball in the laser beam path.
- 7) Online laser safety training is insufficient for work with Class 4 lasers.
- 8) Laser safety training must be re-emphasized in the laboratory by someone who believes in laser safety.
- 9) LSOs should have knowledge and experience appropriate for the laboratories under their charge.
- 10) A laser accident scene should be secured as soon as safely possible to facilitate an accurate determination of the causes of the accident.
- 11) Peers, co-workers, and subordinates must be afforded a non-punitive and non-threatening forum or other means of discussing and/or reporting unsafe practices and conditions in the laser laboratory.

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Meet the Author

Connon Odom earned a BSEE from New Mexico State University in 1965. He became involved with lasers in 1972 while working with a joint service (Army, Air Force, Navy, and Marine Corps) team performing missile electronic countermeasures tests at White Sands Missile Range. He developed the first field worthy lasers employed to exploit susceptibilities of laser guided weapons in static, captive carry, and dynamic drop tests. He has been the laser safety officer for J and DX Divisions at Los Alamos National Laboratory since February 1992.